Efficient, Wide Band, Integrated Lightwave Devices Transmitters for RF-Transmissions

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OBJECTIVES:

1. To build an integrated FM-Laser/discriminator unit as an efficient RF-photonic transmitter.
2. To build a novel low V-π electro-optic modulator based on the photonic crystal structure.

APPROACHES:

STARTING DATES: July 1, 2000. DURATION: 4 years

1. Using the FM gain of the system to compensate the loss and obtain RF insertion gain.
2. Using the photonic crystal structure to obtain slow optical waves and match with the velocity of the RF signal.

Motivation

Analog fiber links vs. microwave links :

Advantages:

- Larger transmission bandwidth
- Immunity to EM interference
- Smaller size as well as weight

Disadvantages:

- larger insertion loss (~ 20 dB) due to the inefficient conversion of RF signals to amplitude-modulated optical signals.

Solutions:

- High power transmitters and high saturation power detectors
- Low V-π modulators

Direct and External Modulations

Direct Modulation: **Link Gain $\propto S_L^2\, S_D^2$** (S: slop efficiency)

Example: Fujitsu DFB: 12 mW fiber pigtailed, slop efficiency: 0.339 W/A, BW=3GHz, RIN: -170 dB/Hz, **<10 dB RF link Loss**, with 128 dB-Hz$^{2/3}$ SFDR

External Modulation: Link Gain $=P_{opt}^2\,[(\pi^2\, t_{ff}^2\, R_{in})/(V_\pi^2)]\, L_f^2\,[R_d^2 R_{out}]$ (t_{ff}: modulator optical insertion loss, R_{in}:modulator drive impedance, L_f: optical loss in the fiber, R_d: photodiode responsivity, R_{out} detector load impedance)

Example: t_{ff}=0.1, R_d=1A/W, L_f=1,

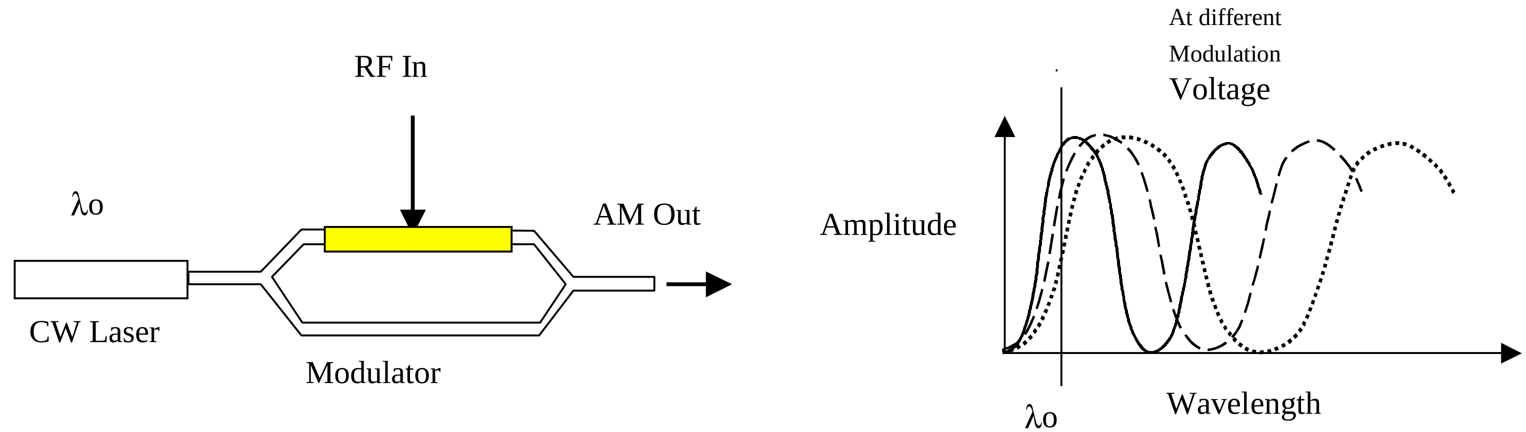
V_π= 1V -> **RF gain** = -17 dB (10 mW), -7 dB (30 mW);

V_π= 0.5V -> **RF gain** = -11 dB (10 mW), -2 dB (30 mW);

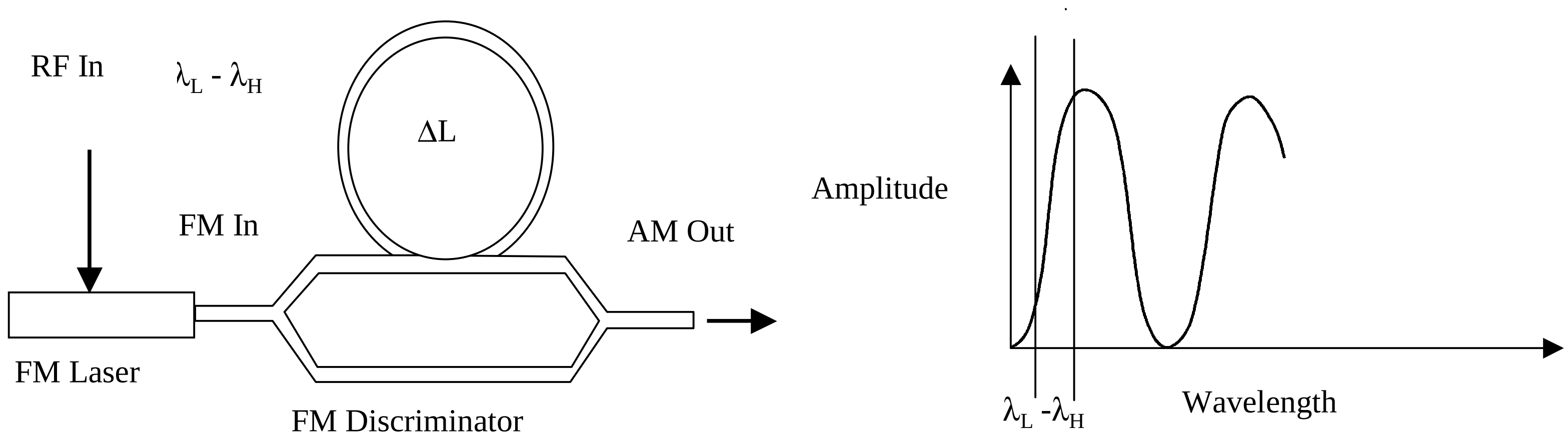
A New Solution

- A new type of lightwave transmitter based on the **frequency modulation** techniques
- Provides **>10 dB RF insertion gain** (Obtained from the "**FM Gain**" of the system
- Operated at **< 0 dBm optical power** (No need for high power to reduce RF loss)
- High spur-free dynamic range (DR_{sp})
- Low noise
- Operating frequency ranges < 10 GHz at this moment. Can be extended to 20 GHz or higher frequencies depending on modulator speeds and linearity limited by Carson's rule.

Principles



Intensity Modulation



FM-based Intensity Modulation

Link Gain

The RF Gain, G= $(RPLK(a_2-a_1)/B)^2$

Where,

R is the responsivity of the photodiode,

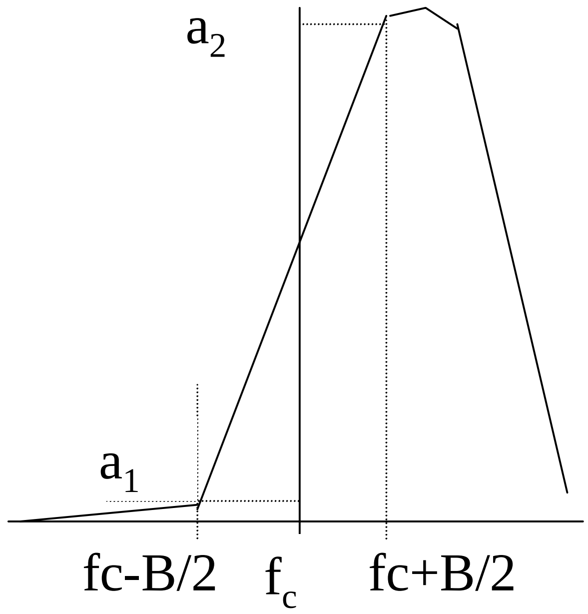
P is the transmitter power,

L is the insertion loss,

K is the FM efficiency (Hz/A) of the FM laser,

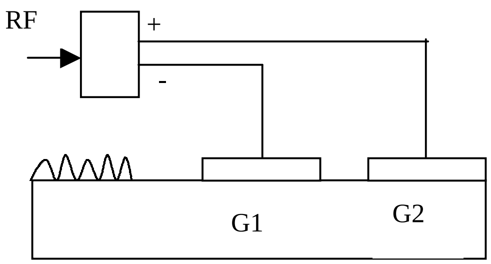
B is the usable bandwidth of the optical filter, $B \geq 2(\beta+1)f_m$

a_2 and a_1 are transfer coefficient at $fc+B/2$ and $fc-B/2$

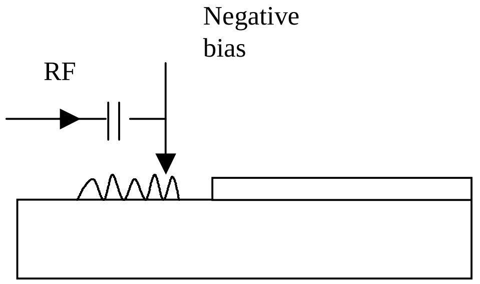


Optical filter transfer function

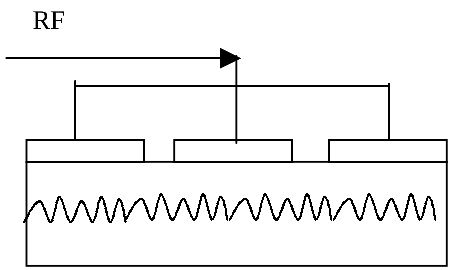
FM Lasers I (Conventional)



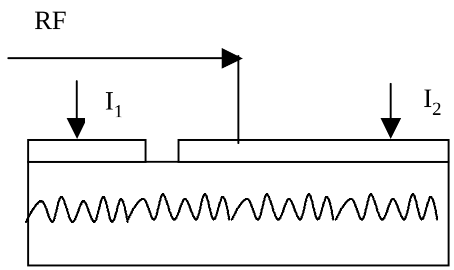
2-section DBR with push-pull modulation



Negatively baised DBR



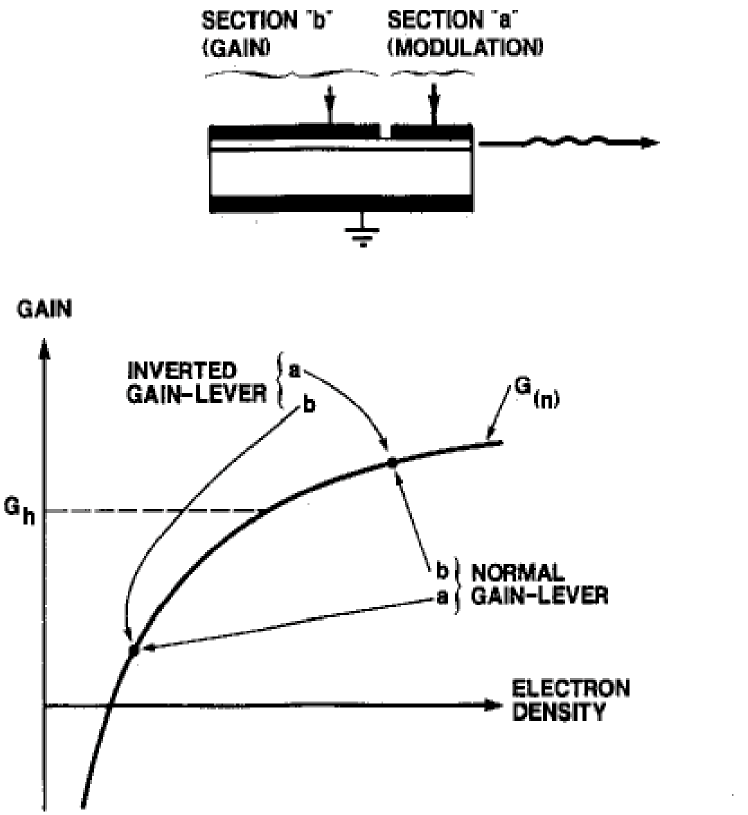
3-section DFB



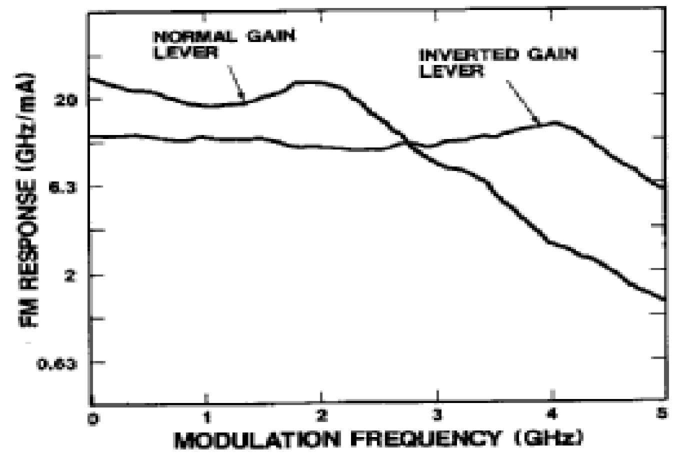
2-section DFB using Gain-lever effect

- All these structures can only achieve about 1GHz/mA FM efficiency in about 1GHz flat region

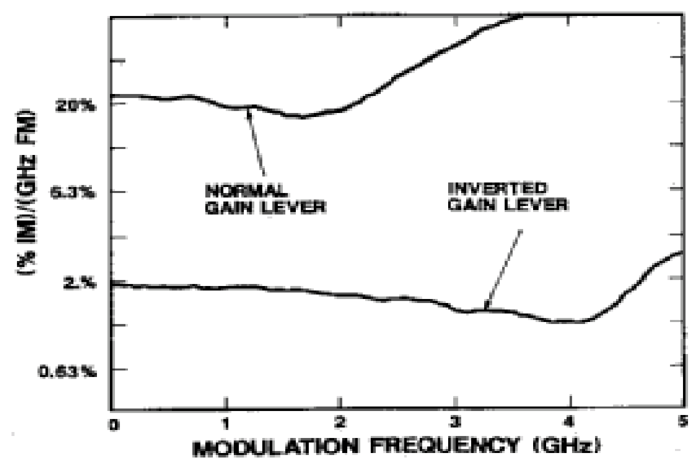
Gain Levering Effects



The gain-lever and the "inverted" gain-lever operation of a two-section quantum well laser. G_k is the threshold gain.



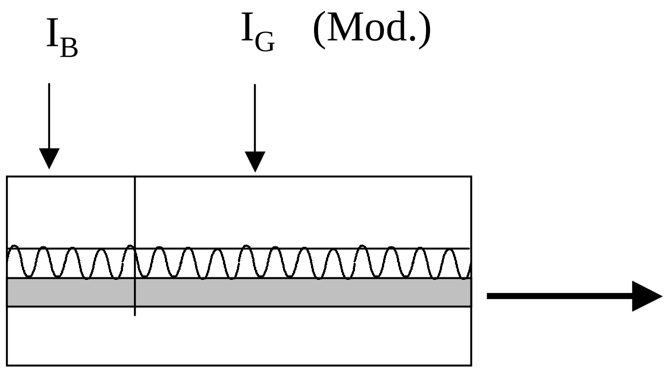
(a)

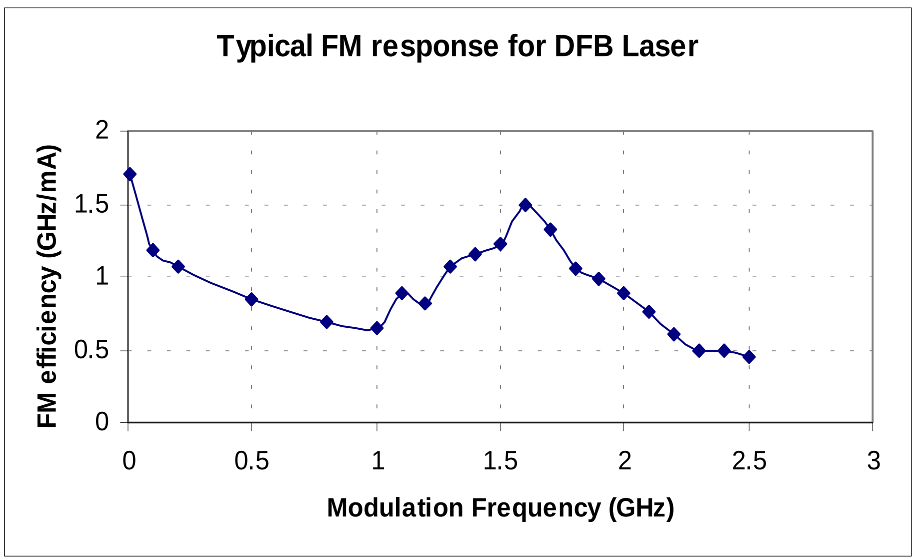


(b)

K. Lau, PTL Aug. 1991

FM Lasers II (Example)



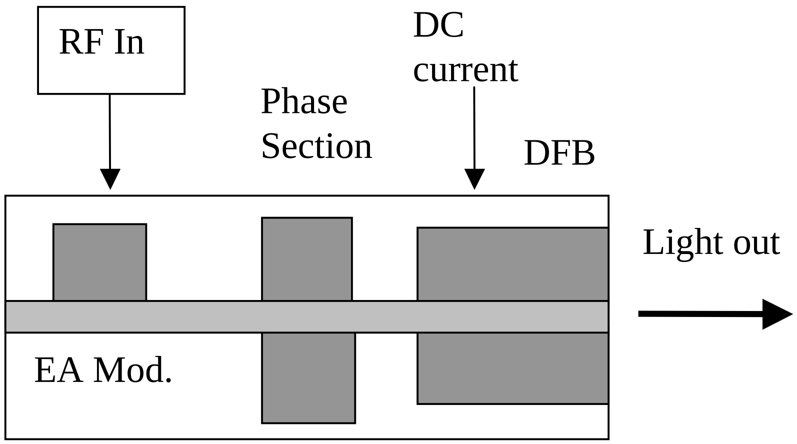


Two-section DFB Lasers:

Using the gain levering effect -

The FM efficiency can be increased (still < 2 GHz/mA). However, the The FM BW is small and the response is not quite flat.

High Efficiency FM Lasers

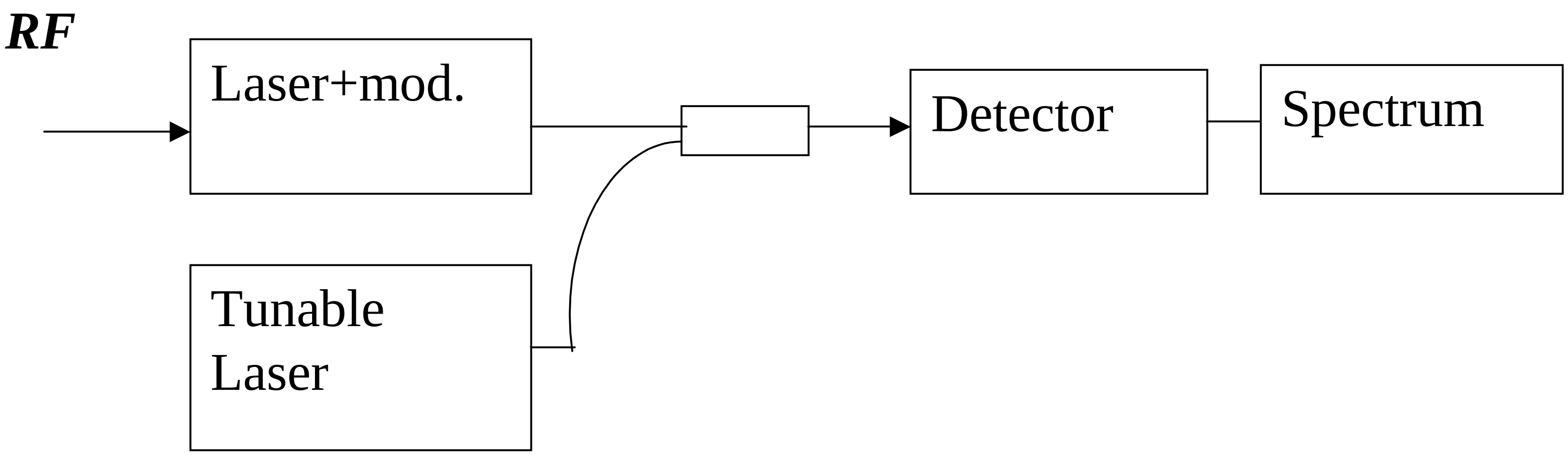


The reflectivity from the facet of the EA modulator contributes to the phase change of the laser and generates a highly efficient FM

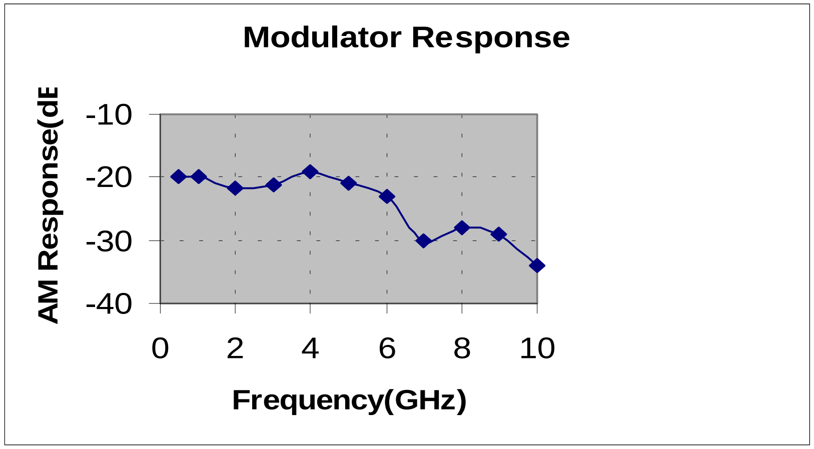
Reference:

X.Huang, A.J.Seeds, et al, “Monolithically integrated Quantum-confined Stark effect tuned laser with uniform frequency modulation response”, Photon. Technol. Lett., v. 10, pp. 1697-1699 (1998).

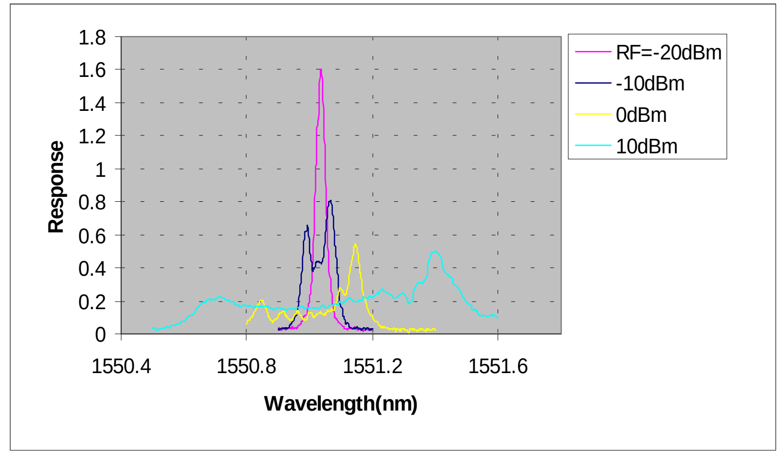
Measurement set up for both AM and FM modulations



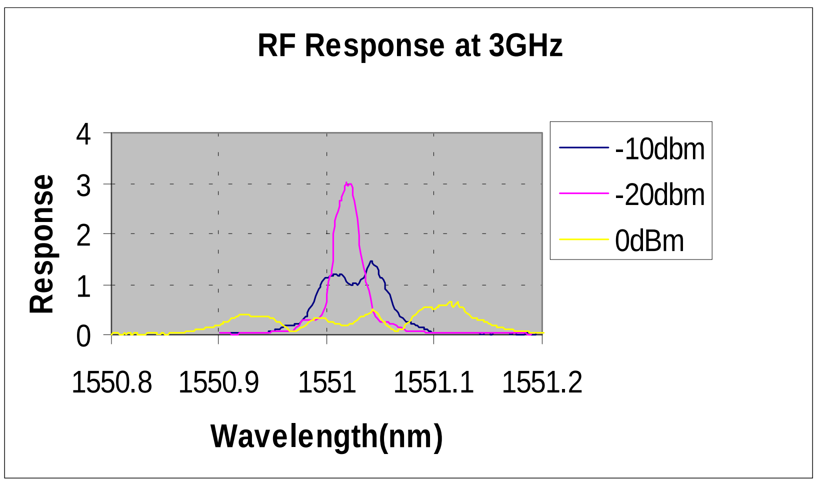
Modulation Characteristics



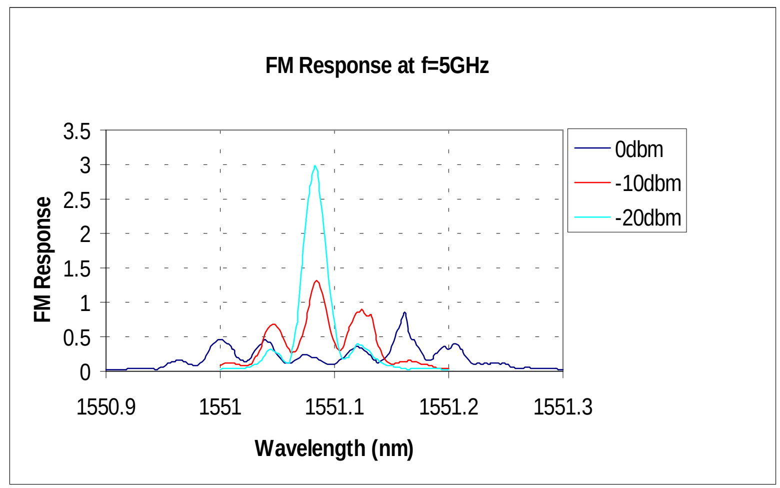
AM Modulator Speed



FM Spectrum at RF=2GHz

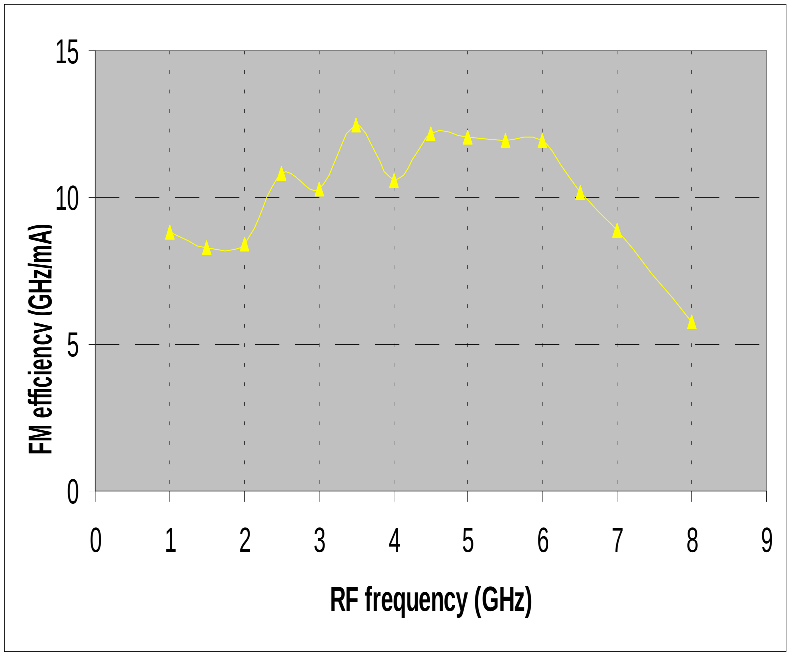


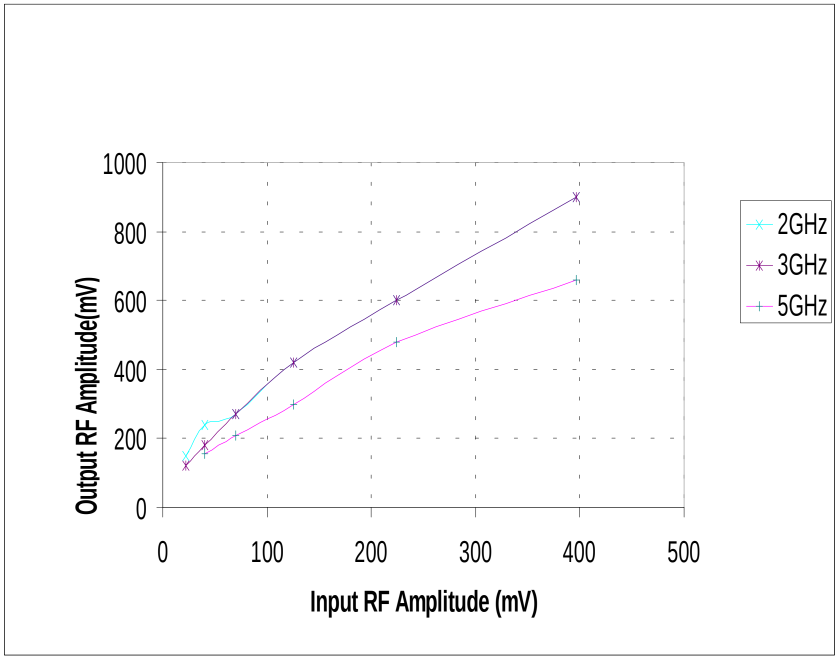
FM Spectrum at RF=3GHz



FM Spectrum at RF=5GHz

FM Response



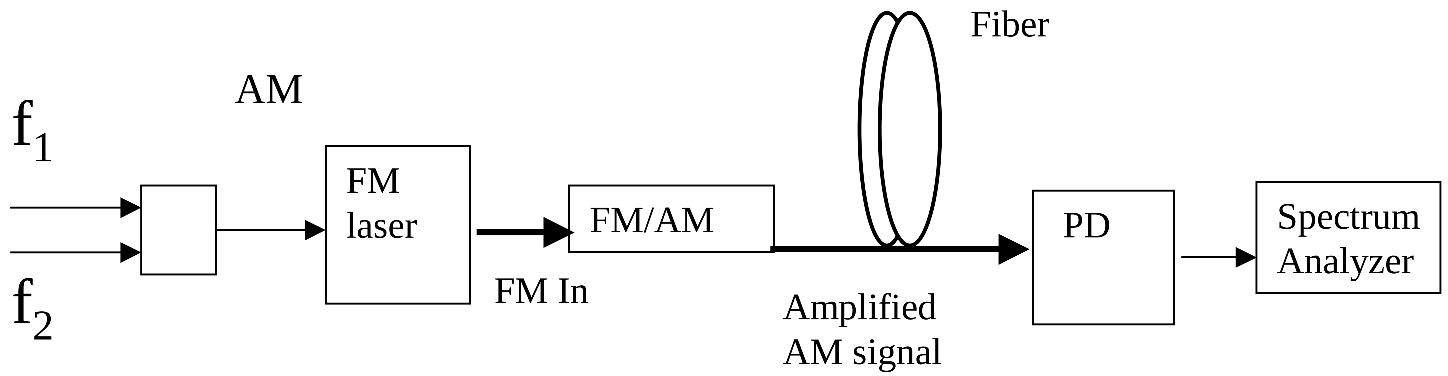


FM efficiency vs. frequency

FM efficiency vs. RF amplitude

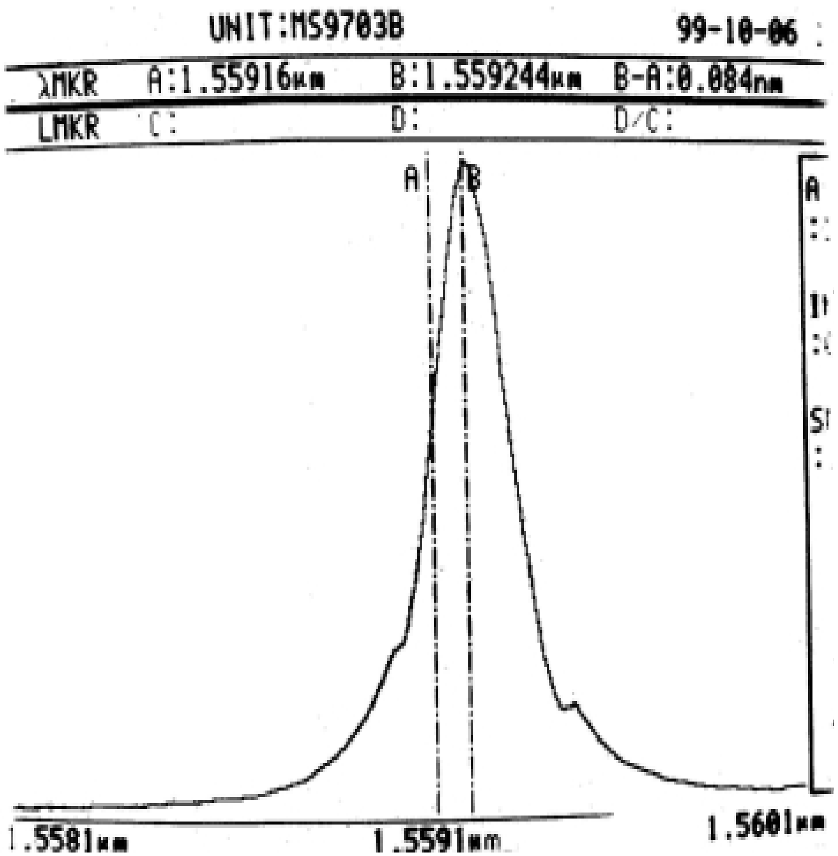
SFDR measurement setup

Two-tone dynamic range testing



f_1=2GHz and f_2=2.5GHz (500 MHz apart for measurements at other frequencies)

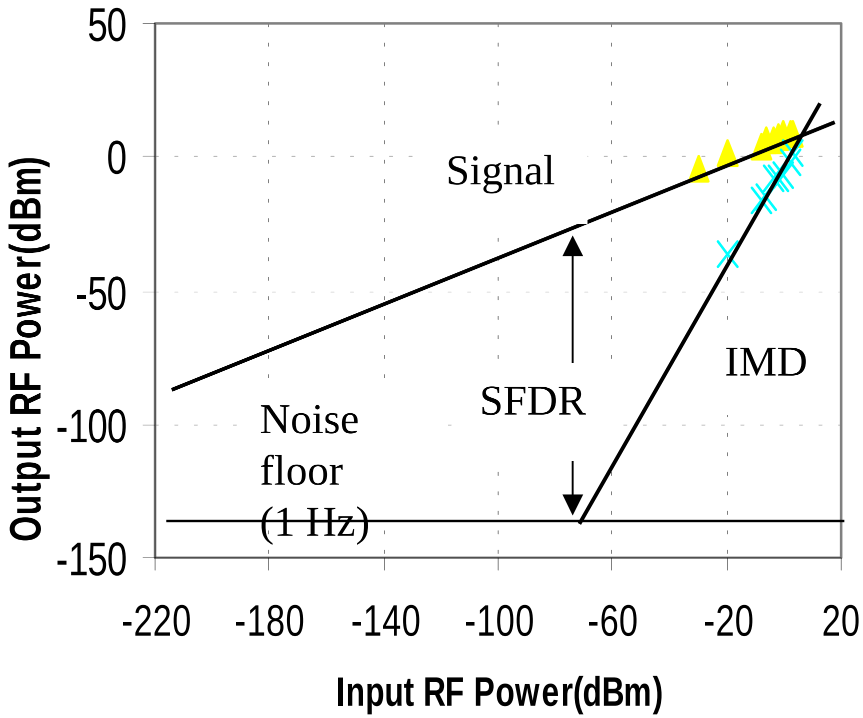
FM-AM Conversion



We used the edge of a narrow band tunable optical filter to perform the FM-AM conversion

the linear region is around 20GHz

SFDR at 2 GHz



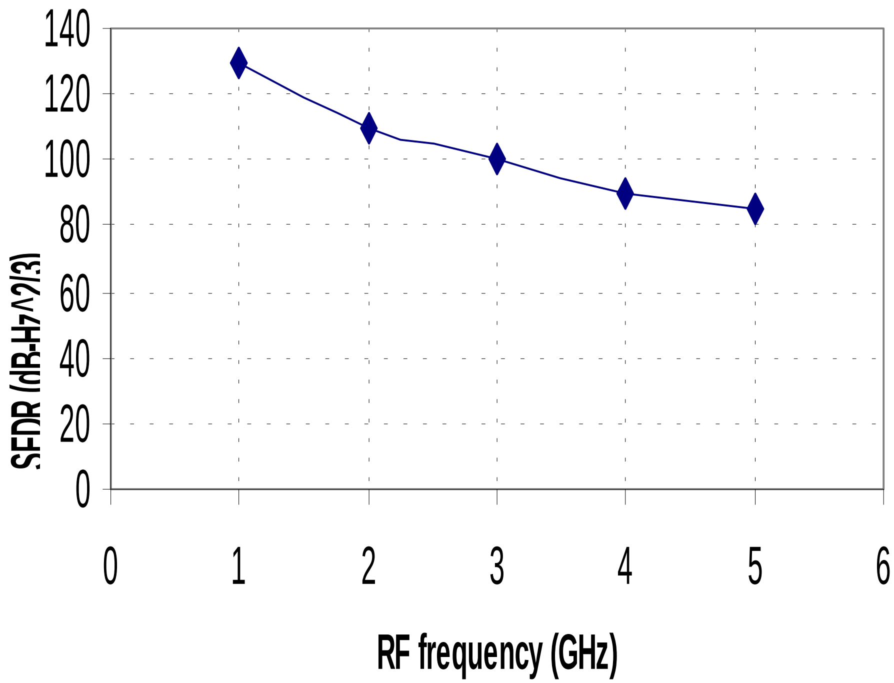
inter-modulation distortion (IMD)-3rd order ($2f_1$-f_2, $2f_2$-f_1)

Note:

1. The RF gain is positive and large (more than 10dB gain, whereas optical power at detector is only -2.3dBm),

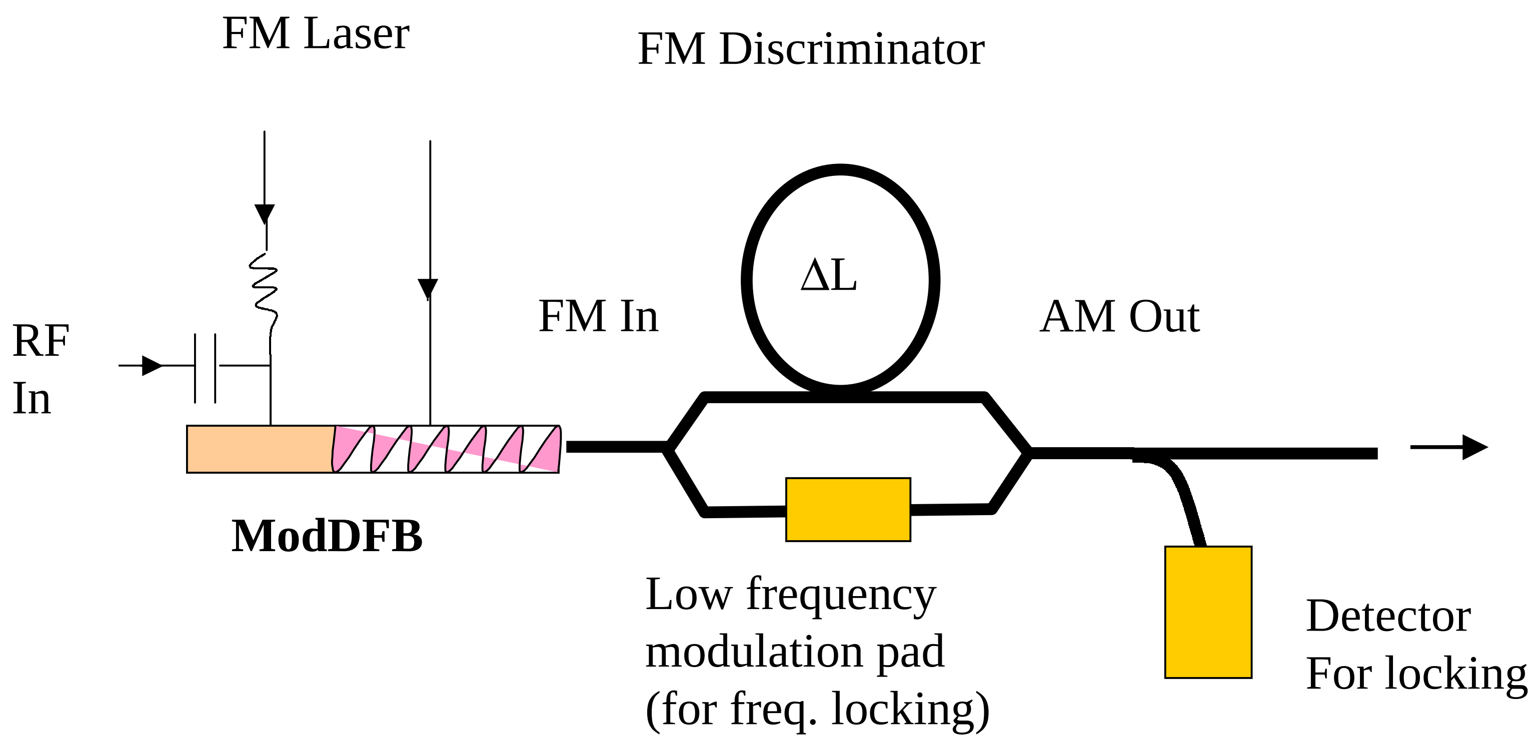
2. The slope of the signal line is not unity because RF gain varies with input power

SFDR at other frequencies

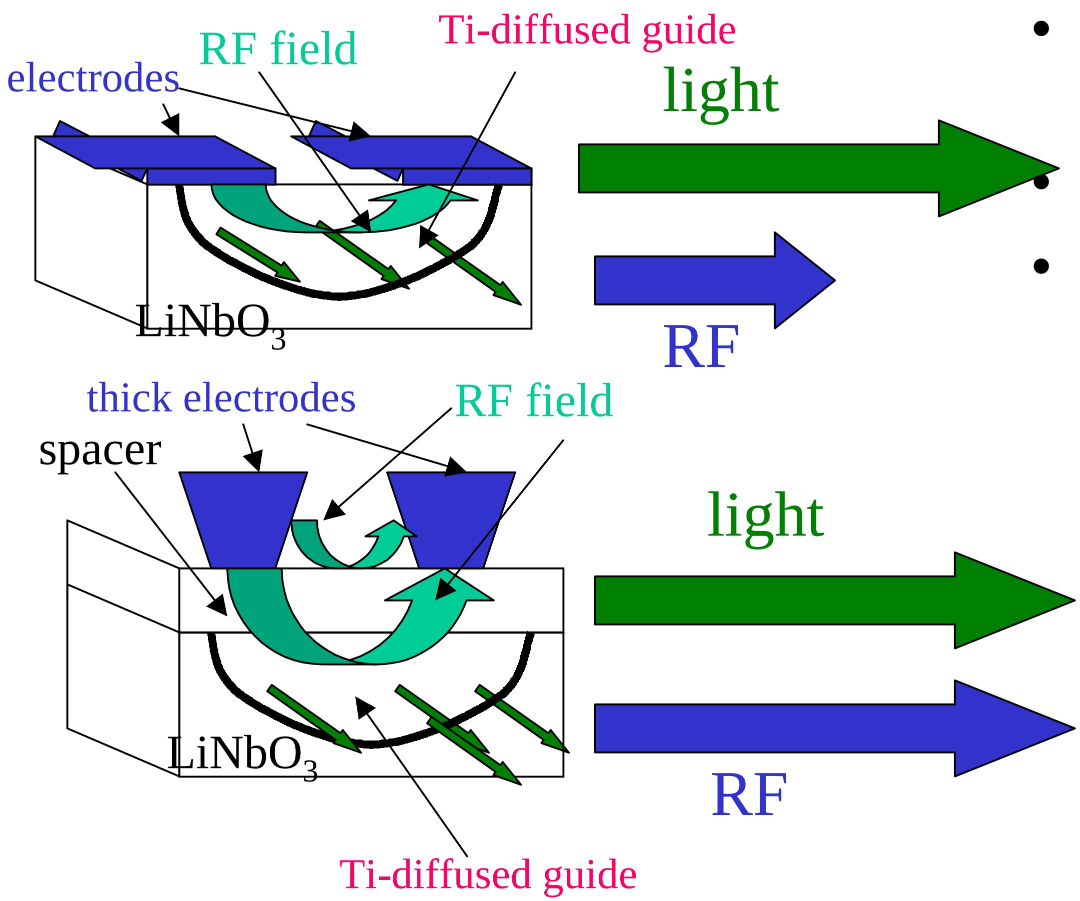


More than 90dB SFDR can be achieved up to 5GHz, where the AM response starts to drop. The nonlinearity of the system is reasonable.

Planed Integration

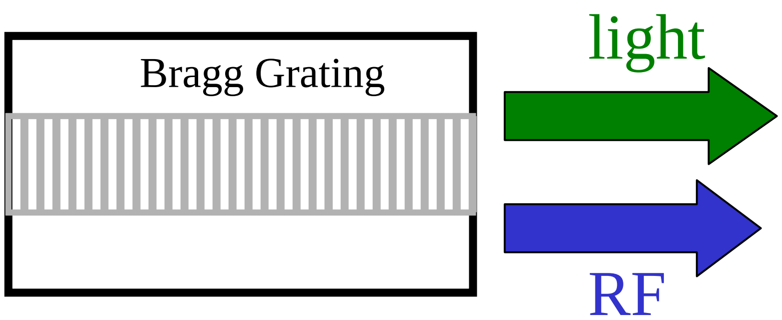


Novel Electro-Optic Modulator

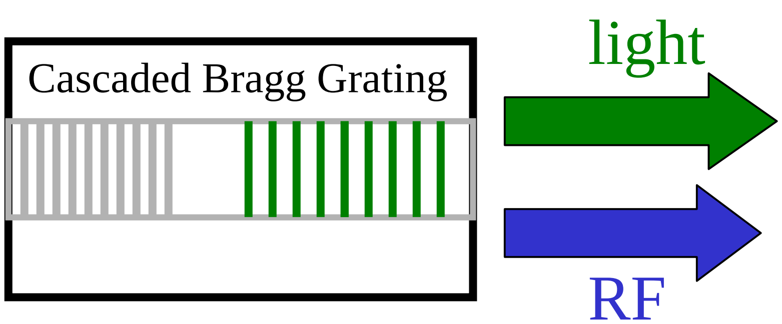


- It is necessary to match velocities of RF and light
- In $LiNbO_3$ $v_{opt} \sim 2.2 v_{RF}$
- Velocities are normally matched by using thick electrodes and spacer with lower ε - this way RF propagates partially in the air.
  - Overlap with light mode is small
  - Difficult to obtain 50Ω impedance.

What is proposed.

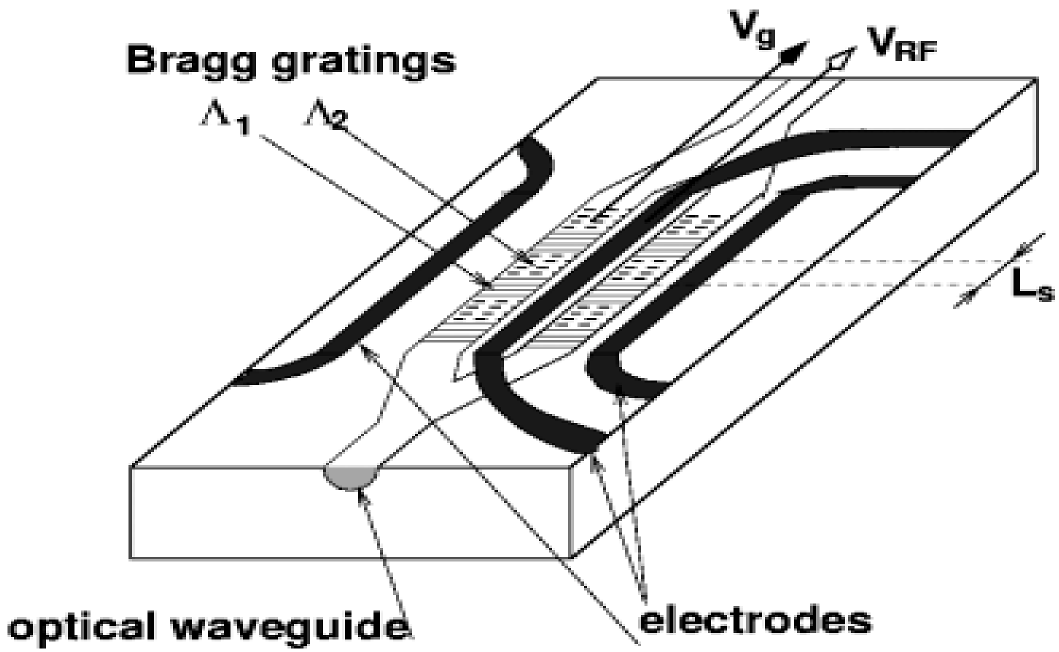


The group velocity
dispersion is too high -
use cascaded Bragg gratings.



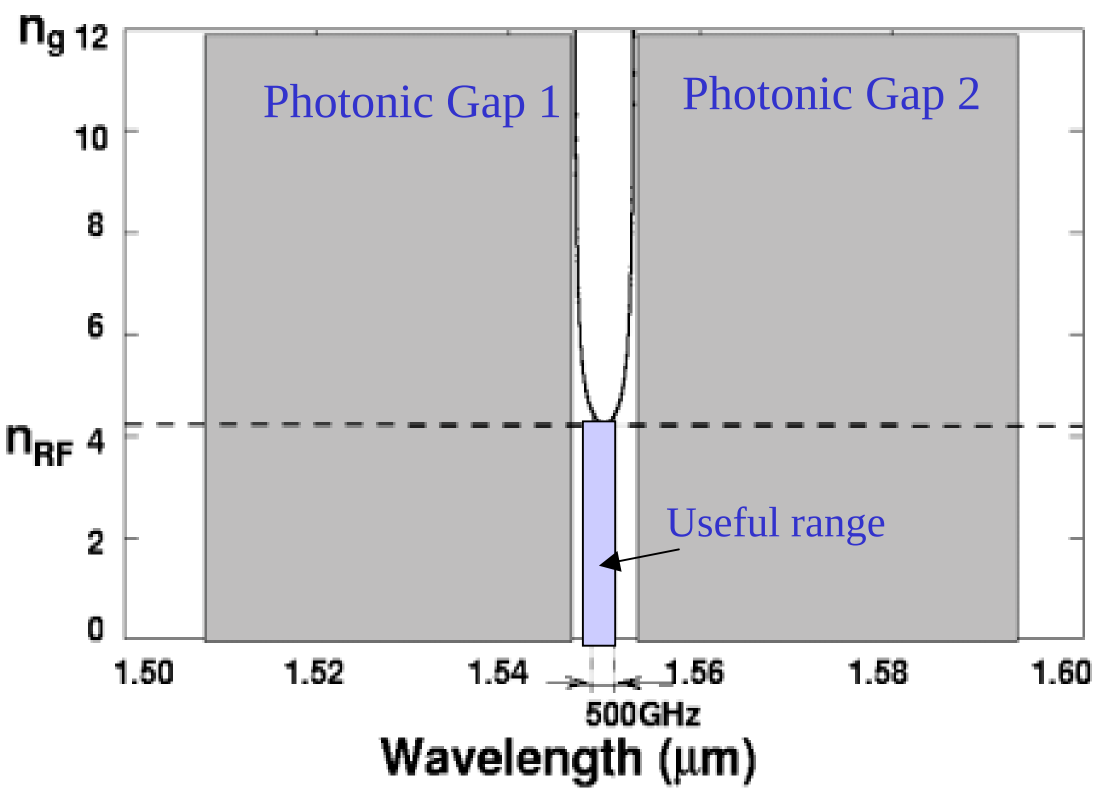
- We propose to slow down the optical wave instead of accelerating the RF wave using Bragg grating
- Advantages:
  - no need for spacer or thick electrodes = larger overlap between RF and light waves
  - longer interaction time = larger effective length
  - easy to design 50Ω impedance.

Proposed Design



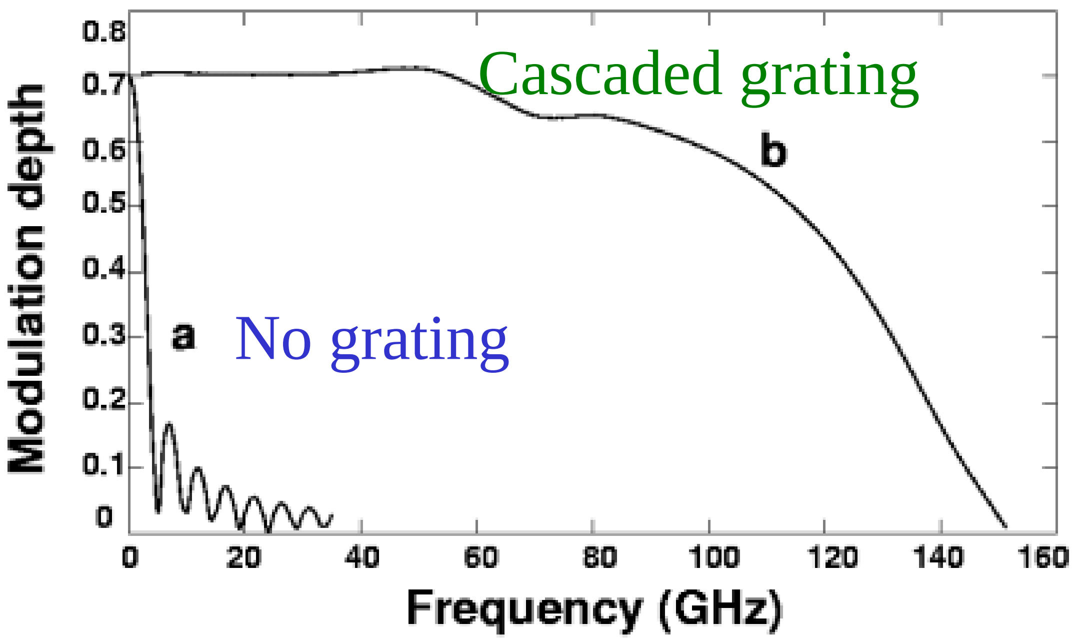
- Design wavelength: 1.55 µm
- Bragg grating periods are .35 and 0.36 µm
- Segment length 1mm
- Total length 2cm
- Number of segments 20

Matching the group index of light and RF index



- The second order GVD is cancelled - only the third order term survives
- The width of useful range depends on the depth of index modulation - 1% here.

Results of the modeling



- Expected V_π~1V
- Impedance 50Ω
- Bandwidth ~75GHz

Advantages of the proposed scheme

- The effective interaction time is increased by a factor of ~2.2 - equivalent to the reduction of V_π by the same amount
- The overlap between the RF field and optical mode can be large - V_π is reduced by another factor of ~1.4-1.6
- Two matching tasks are decoupled: -velocities are matched by proper design of the grating and impedance matching is accomplished independently by the electrodes design.

Planned course of work:

- Design and fabricate test Bragg structures without electrodes
- Measure the light group velocity
- Design electrodes
- Test the modulators